STUDY ON ATTITUDE DETERMINATION ALGORITHM FOR THE ENERGIZATION AND RADIATION IN GEOSPACE (ERG) SPACECRAFT

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The Energization and Radiation in Geospace (ERG) spacecraft, which is provisioned to be launched in 2016 summer, will explore how relativistic electrons in the radiation belts are generated during space storms [1]. The spacecraft will be sun-oriented and spin-stabilized with an approximate 7.5 rpm spin rate. This paper discusses the attitude determination algorithm design for the spacecraft. First, an Unscented Kalman Filter (UKF) based algorithm is given and demonstrated with simulations for estimating the attitude and attitude rates of the spinning spacecraft. Then, the coning angle caused by the mismatch between the geometric and actual spin axes is estimated using a newly proposed Singular Value Decomposition for Coning (SVD-C) method. Effects of other biases on the estimation algorithm are examined.

Spin stabilization as a mean of attitude control has a long history which goes back to the early days of space exploration. If we check [2], which was published in 1978, we can see an extensive discussion on attitude estimation for spinning spacecrafts and specifically spin-axis estimation. Later on, in next few decades spin-stabilization lost its popularity and displaced by three axis control methods. Today, as the small satellite missions pervade, spin-stabilization has become to be popular once more because of its simple nature fit to nano and micro satellites. Yet, the attitude estimation for spinning spacecrafts is an immature research area despite the publications in recent years [3-8].

The SpinKF algorithm that is described in [4] is the main on-ground attitude estimator for recent missions of the National Aeronautics and Space Administration (NASA), such as the Van Allen Probes [5]. The SpinKF is an Extended Kalman Filter (EKF) by nature but it is different in that the used state vector. It avoids using the quaternion and instead uses a seven parameters angular-momentum based state vector. If we use the standard EKF for a spinning spacecraft with attitude and attitude rates as the states, the first order linear approximations might be violated. This is because of the rapidly changing states. On the other hand, use of angular momentum based state vector allows the EKF stay within the linear state space regime since the angular momentum of the spacecraft will be changing very slowly [4-7]. Quite complicated models that have to be used in the SpinKF are the main disadvantage of this filter.

The UKF is a nonlinear filtering method, accuracy of which has been shown for three-axis attitude estimation. It does not need any linearization and is valid to higher order expansions than the EKF. Compared with the EKF's first-order accuracy, the estimation accuracy of UKF is improved to the third-order for Gaussian data and at least second-order for non-Gaussian data [9]. Rapidly changing states and/or high nonlinearity does not violate any assumption lying on the basis of the UKF.

In the first part of this paper, we discuss the performance of the UKF as the main on-ground attitude estimation algorithm for the ERG spacecraft. As to our knowledge, there is no spin spacecraft mission that has employed the UKF so far. The ERG has a V-slit star scanner (SSC) and two spin sun aspect sensors (SASS) onboard. The SASSs provide one measurement per spin whenever the sun is visible. The UKF is tested for different SSC measurement sequences regarding the star visibility analysis for the spacecraft's orbit. In the second part, we propose the SVD-C algorithm for estimating the coning angle. We assume that the coning angle (or dynamic imbalance) will be the main disturbance bias affecting the attitude accuracy. The SVD-C uses the attitude rate estimates of the UKF and estimates the small Tait-Bryan angles representing the coning (Fig.1). We show that the algorithm converges to the actual coning angles with arc-second accuracy. We compare the algorithm with another simple coning estimation method that is similar to the one given for the Magnetospheric Multiscale (MMS) mission [6]. We perform sensibility analysis for the overall attitude determination approach when the sensors are misaligned and measurements are subjected to biases.

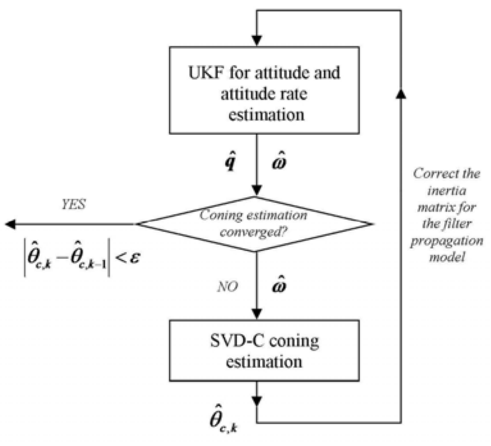

Figure 1. Coning angle estimation approach

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